



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/SE97/00752 <b>(22) International Filing Date:</b> 5 May 1997 (05.05.97)  <b>(30) Priority Data:</b> 9601750-4                      7 May 1996 (07.05.96)                      SE  <b>(71) Applicant (for all designated States except US):</b> SAMBA SENSORS AB [SE/SE]; Flöjelbergsgatan 14, S-431 34 Mölndal (SE).  <b>(72) Inventor; and</b> <b>(75) Inventor/Applicant (for US only):</b> ENGSTRÖM, Olof [SE/SE]; Hindbyvägen 1, S-430 63 Hindås (SE).  <b>(74) Agents:</b> GRAUDUMS, Valdis et al.; Albihn West AB, P.O. Box 142, S-401 22 Göteborg (SE).		<b>(81) Designated States:</b> JP, KR, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i> <i>In English translation (filed in Swedish).</i>
<b>(54) Title:</b> DEVICE FOR ELECTRO-OPTICAL PRESSURE MEASUREMENT		
<b>(57) Abstract</b>		
<p>The device is a pressure sensor based on optical interference in a sensor body, with a cavity created between two parts spaced apart from each other, where the light signal is transported directly in vacuum, air, gas, liquid, another gas medium or a transparent solid material from a source of light to the sensor body and subsequently in the same media to a photo detector which outputs an electrical signal which constitutes a measurement of the pressure which is desired to measure.</p>		
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## TITLE:

5 Device for electro-optical pressure measurement.

The present invention relates to a device for electro-optical measurement of pressure according to the preamble of claim 1.

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The device is a pressure sensor based on optical interference in a sensor body with a cavity created between two parts spaced apart from each other, where the light-signal is transported directly, in vacuum, air, liquid, another gas-medium or transparent solid material, from a light source to the sensor body and subsequently in the same media to a photo detector which outputs an electrical signal which constitutes a measurement of the pressure one wishes to measure. There is an earlier patent application (application PCT/SE93/00393) which describes a device based on a sensor body which is constructed according to the same principles, where the optical signal is transported in an optical fibre. In the present invention, a number of possibilities are shown of creating a sensor where the optical fibre is eliminated. In so doing, a sensor is obtained with an electrical output signal where the signal conversion from optical to electrical takes place close to the point of measurement. The invention is intended for those cases where the optical fibre which is part of the device according to application PCT/SE93/00393 causes disadvantages, and where it is desired to utilize a pressure sensor with an electrical output signal but with the advantages of the optical sensor principle.

35 The sensor body included in Fig. 1 can be constructed in various different ways. The version shown in Fig. 1 consists of two parts 1, 2 separated by a molecularly applied layer 3 with a geometrical shape such that a cavity 4 is formed between the two parts. The width of the cavity is adapted to the wavelength of the light so that optical

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interference occurs in it (see application PCT/SE/00393). A suitable method for manufacturing the sensor body 1, 2, 3 is to use silicon technology in the way described in application PCT/SE/00393.

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There are various earlier known versions of optical sensors for measurement of pressure. Regardless of the amount of parts which are used for joining together the sensor body, the sensor body according to the invention is given the reference "1, 2, 3".

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The principal construction of the device is shown in Fig. 1. The sensor body 1, 2, 3 with the cavity 4 is joined together with an optical transmitter-receiver unit 6 via a medium of vacuum, air, liquid, another gas or transparent solid material 5 for the transport of the optical signal. The distance between the transmitter-receiver unit 6 and the sensor body 1, 2, 3 can vary depending on the intended application, from a version where the transmitter-receiver unit 6 is placed in direct contact with the sensor body 1, 2, 3 to larger distances, where the length of the material 5 can be determined by, for example, a tube. The transmitter-receiver unit 6 consists of a light source, which emits light through the media 5 towards the sensor body 1, 2, 3. The light penetrates the part 1, interferes in the cavity 4, is reflected against the part 2 and is returned to the media 5, following which it is received in the transmitter-receiver unit 6 by a photo detector which outputs an electrical signal. The intensity of the returned light depends on the interference conditions inside the cavity 4, which depend on the depth of the cavity, which in turn is decided by the bending of the part 2 due to the external pressure. The electrical signal which is output from the photo detector thus becomes a measurement of the external pressure. The transmitter-receiver unit, consisting of light source and photo detector can also

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possibly contain an electronic circuit for the feeding of these two components and for processing of the electrical signals from the photo detector. Such electronics, which can be designed as an integrated circuit, can for example  
5 comprise one part for eliminating noise, one part for analogue-to-digital conversion of the electrical signal, or a part for the linearization of the electrical sensor signal. The combination of the parts which the device according to Fig. 1 comprises can be varied in a number of  
10 ways, as stated in the claims and in the text below.

Fig. 2 shows a version of the device of Fig. 1, where a light source 7 is attached directly to the sensor body 1, 2, 3 so that the light 12 from the light source 7 after  
15 interference in the cavity 4 is reflected back (13) to the photo detector 9. The light source can, for example, be a light emitting diode fed from the voltage source 8, and the photo detector can be a photodiode fed from the voltage source 10 with an ampere meter 11 in the latter circuit in  
20 order to obtain a current through the photodiode as a measurement of the pressure which affects the sensor body 1, 2, 3.

Fig. 3 shows a version where the light source 7 and the photodiode 9 are placed on the surface of and electrically  
25 connected to an integrated circuit in the shape of a semiconductor chip 14, which contains the electronics described in the paragraph above. Another similar possibility is shown in Fig. 4, where the light source 7  
30 has been embedded in a recess in the semiconductor chip 14, and where the photo detector 9 is designed as a photodiode which is integrated in the semiconductor chip.

Fig. 5 shows a version where the sensor body 1, 2, 3 has  
35 been separated from the transmitter-receiver unit 6, which can be any of the versions described above in connection

with the drawings above or below, by placing the two units at separate ends of a tube-shaped spacing unit 15 with a transmission hole 16. The advantage of this geometry is that the transmitter-receiver unit 6 is separated from the point of measurement where the sensor body is located, in such cases where the point of measurement is in contact with high temperatures, aggressive chemical media or other severe environments. The light is here transported in the media which exists inside the tube: vacuum, air, gas, liquid or some other substance which is transparent to the wavelength of the light in question. Furthermore, the spacing unit 15 is preferably joined to the sensor body 1, 2, 3 using thermic or anodic bonding.

Fig. 6 shows a version of the above where the medium whose pressure it is desired to measure is led into the transmission hole 16 of the tube 15 through an opening 17, where the sensor body 1, 2, 3 and the transmitter-receiver unit 6 are held in place by the end-sealings 18, 19.

Fig. 7 shows a practical solution, where the tube 15 with the transmission holes 16 is positioned inside a casing where it is held in place by the end-sealing 21. The casing 20 has a screw-threading 22 for attachment. The transmitter-receiver unit is represented in the figure by a casing 23 with the light source 7 and the photo detector 9 fitted and electrically connected to the connecting pins 24 for connection to an electronic circuit outside of the sensor device. It is of course possible to replace the device 7, 9, 23, 24 with one casing which contains an integrated circuit with a light source and photodiode as described above. The sensor body 1, 2, 3 is sealed against the inside of the casing 20 with a sealing ring 25. The length of the tube 15 can be varied depending on the intended application. For those cases where the temperature of the point to be measured is not sufficiently high to

negatively affect the transmitter-receiver unit, the tube 15 can be shortened in order to obtain maximum efficiency in the optical transfer between the transmitter-receiver unit 9, 7, 23, 24 and the sensor body 1, 2, 3.

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If the sensor body is made from a semiconducting material, for example silicon, the light source and photo detector can be integrated as pn-transitions with the sensor body 1, 2, 3 itself, in the way shown in Fig. 8. This can be achieved by giving the areas 26 and 27 opposite dopings as compared to parts 1 and 2. If, for example, part 1 is a semiconductor of the n-kind, the area 27 is doped to become the p-kind and vice versa. In this way, pn-transitions between the areas 1 and 27 are created, and in a corresponding manner between the areas 2 and 26. The pn-transition 2, 26 can for example be used as a photodiode by reverse-connecting it. In order to achieve this, a contact doping 28 with the same kind of charge as part 2 is made, but with a higher concentration of doping substance in a manner which is conventional within the IC technology. The areas 26 and 28 can thus galvanically be connected to a voltage source 29 connected in series with an ampere meter 30. In a corresponding manner, a contact doping 31 can be made for galvanic connection of the pn-transition 1, 27 via a voltage source 32, so that the pn-transition 1, 27 becomes forward-connected. The pn-transition 1, 27 will thus function as a light emitting diode. The emitted light 33 interferes in the cavity and is transported onwards (34) to the photodiode 2, 26 where its intensity is detected and becomes a measurement of the external pressure when the depth of the cavity 4 varies due to a variation in pressure in the earlier described manner. As mentioned above, the sensor body 1, 2, 3 can also be constructed without the spacing layer 3 but with an otherwise if the parts 1 and 2 are made from n-type and p-type materials respectively.

The luminescent properties of silicon are, as a rule, very weak although a forward-connected pn-transition often causes a light emission which is easily detectable using a photodiode in the same material. Recently, there has been  
5 some research in order to create more efficient light emitting diodes in silicon. Such structures can be obtained by doping the silicon with a suitable recombination centre, for example erbium (see E.King and D.G.Hall, Physical Review B, 50, 10661 (1994) and references therein). In this  
10 way, light emission is obtained in a wavelength area which normally is not detectable using silicon photodiodes. The sensitivity of the photodiode can, however, be increased by doping it too with a generation centre which has an energy level close to the middle of the bandgap energy of silicon  
15 (see for example O.Engström and H.G.Grimmeiss, Journal of Applied Physics 47, 4090 (1976)).

A version of the device of Fig. 8 is shown in Fig. 9. The doping 26 of the photodiode is here in the same part 2 as  
20 the light emitting diode 27. The light 33 from the light emitting diode 27 interferes in the cavity 4 but is now reflected back to the photodiode 26. Both the light emitting diode and the photodiode are in this case connected to the same contact doping 36, but the light  
25 emitting diode is forward-connected by the voltage source 35 while the photodiode is reverse-connected by the voltage source 29 at the same time as its current is measured with the ampere meter 30 connected in series. Fig. 9 also shows a possibility of simultaneously measuring temperature in a  
30 component according to Fig. 8 or 9. A pn-transition 1,40 is created which is not affected by the light from the light emitting diode 2, 27, by placing it on the sensor body in such a way that it is optically screened from the light emitting diode 2, 27. In the figure, this has been shown by  
35 placing the pn-transition 1,40 close to the edge of the sensor body. Other positions are also possible, where

optical contact is prevented between the light emitting diode 2, 27 and the pn-transition 1,40. By reverse-connecting the pn-transition 1,40 by means of a galvanic coupling to the contact doping 37 via the voltage source 38  
5 connected in series with the ampere meter 39, the current measured by the ampere meter becomes a measurement of the temperature of the sensor body. In this way, a sensor is created for the simultaneous measurement of pressure and temperature. As mentioned above, the sensor body 1, 2, 3  
10 can also be constructed without the spacing layer 3 but with an otherwise if the parts 1 and 2 are made from n-type and p-type materials respectively.

Fig. 10 shows a version of the device of Figs. 8 and 9  
15 where the sensor body is designed as a pn-transition with a cavity 42 in the transition between the p-type semiconductor 40 and the n-type semiconductor 41. In each of the parts 40 and 41 there are dopings 43 and 44, where 43 is an n-type doping and 44 is a p-type doping. In this  
20 way, pn-transitions 43, 40 and 44, 41 are also created. Two contact dopings 45 and 46 are injected in the two parts 40 and 41, and voltage sources 47 and 49 are galvanically connected between the contact dopings and the pn-transitions in series with one ampere meter each 48 and 50  
25 so that, as can be seen in Fig. 10, the two pn-transitions 44, 41 and 43, 40 become reverse-connected. Furthermore, the two contact dopings 45 and 46 are connected to an external voltage source 51 so that the pn-transition which is formed by the two parts 40 and 41 becomes forward-  
30 connected. The device in Fig. 10 then corresponds to the equivalent circuit diagram shown in Fig. 11. The numbering of the electrical nodes in Fig. 11 corresponds to the numbered areas of Fig. 10. The structure in Fig. 10 thus constitutes three pn-transitions, where one is forward-  
35 connected and emits light while two are reverse-connected and detect light. By choosing polarization of the voltage

sources 47, 49 and 51, the light emitting diode function and the photodiode function can be arbitrarily chosen among the three pn-transitions. Furthermore, by placing one of the superficially located pn-transitions 43, 40 or 44, 42 so that they are optically screened from the pn-transition which has been chosen to be a light emitting diode, it can be used for measuring temperature according to the principle described in connection with Fig. 9.

10 It should be pointed out that the term "direct optical contact" comprises designs where a transmitter-receiver unit is arranged so that no transmission via an optical fibre is necessary. This can be done, for example, by arranging a light source in direct connection to the sensor body (compare Fig. 1) or by a transmitter-receiver unit being so arranged that there is optical contact via a transmission aperture which might be filled with a transparent media (compare Fig. 5).

## CLAIMS:

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1. Device for measuring pressure, comprising at least two parts (1, 2) spaced apart from each other by a molecularly applied layer (3), which parts are located one on either side of a cavity (4) or a cavity constructed in a pn-transition (40, 41, 42), in this way constituting a sensor body (1, 2, 3) and an optical transmitter-receiver unit (6), characterized in that the optical transmitter-receiver unit (6) is in direct optical contact with the cavity (4), the width of which is affected by a pressure so that the light from the optical transmitter-receiver unit interferes inside the cavity (4), is modulated by it, is detected by the transmitter-receiver unit (6) and thus constitutes a measurement of the pressure in the shape of an electrical signal from the transmitter-receiver unit (6).

2. Device according to claim 1, characterized in that the optical transmitter part in the form of a light source (7), and the optical receiver part (9) in the form of a photodiode are in direct optical contact with the sensor body (1, 2, 3) by being mechanically attached to the sensor body.

3. Device according to claim 1, characterized in that the optical transmitter (7) and receiver (9) parts are mechanically attached to an integrated electronic circuit (14) for the electrical feeding of the transmitter (7) and the receiver (9), and for the processing of the electrical signals from the receiver (9).

4. Device according to claims 1 and 3, characterized in that the optical transmitter unit (7) is fitted in a recess in the

integrated circuit (14) and/or in that the receiver unit (9) is integrated in the circuit (14) as a photodiode.

5. Device according to claim 1,  
5 c h a r a c t e r i z e d i n that the transmitter-receiver unit (6) and the sensor body (1, 2, 3) are fitted one at either end of a spacing unit (15) with a hole (16) for the transport of light signals between the transmitter-receiver unit (6) and the sensor body (1, 2, 3).

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6. Device according to claim 5,  
c h a r a c t e r i z e d i n that the spacing unit (15) is attached to the sensor body (1, 2, 3) by means of thermic or anodic bonding.

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7. Device according to claim 5 or 6,  
c h a r a c t e r i z e d i n that the hole (16) comprises a medium which is vacuum, air, gas, liquid or another substance which is transparent to the wavelength of  
20 the light in question.

8. Device according to any of claims 5-7,  
c h a r a c t e r i z e d i n that the light transporting hole (16) via an aperture (17) is in contact with a  
25 surrounding media, the pressure of which is to be measured.

9. Device according to any of claims 5-8,  
c h a r a c t e r i z e d i n that the spacing unit (15) is fitted in a jacket (20) with a sealing (25) between the  
30 sensor body and the jacket, and with the sensor body fitted so that it is in optical contact with a transmitter-receiver unit at the other end of the spacing unit (15).

10. Device according to claim 1,  
35 c h a r a c t e r i z e d i n that the transmitter unit (1, 27) is designed as a light emitting diode and the

receiver unit (2, 26) is designed as a photodiode, both of which are integrated in parts 2 and 1 respectively of the sensor body by being designed as pn-transitions in their respective parts of the sensor body.

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11. Device according to claim 10,  
c h a r a c t e r i z e d i n that a further pn-  
transition is created in the sensor body for measuring the  
temperature of the sensor body.

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12. Device according to claim 1 with the sensor body  
designed as a pn-transition (40, 41, 42),  
c h a r a c t e r i z e d i n that two further pn-  
transitions are created in parts 40 and 42 so that any of  
15 the three pn-transitions can be a light emitting diode  
while the two others can be photodiode and temperature  
measuring unit, respectively.

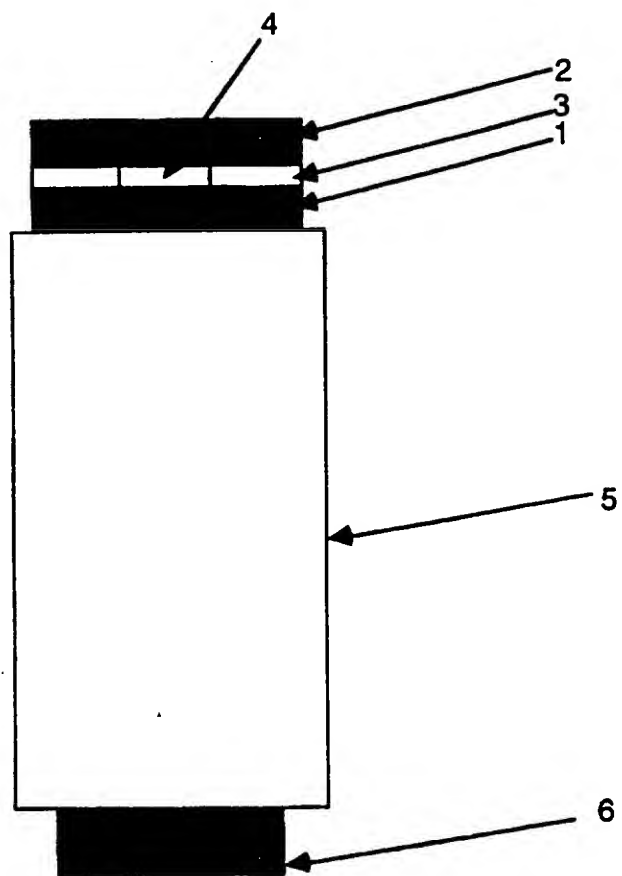


Fig. 1

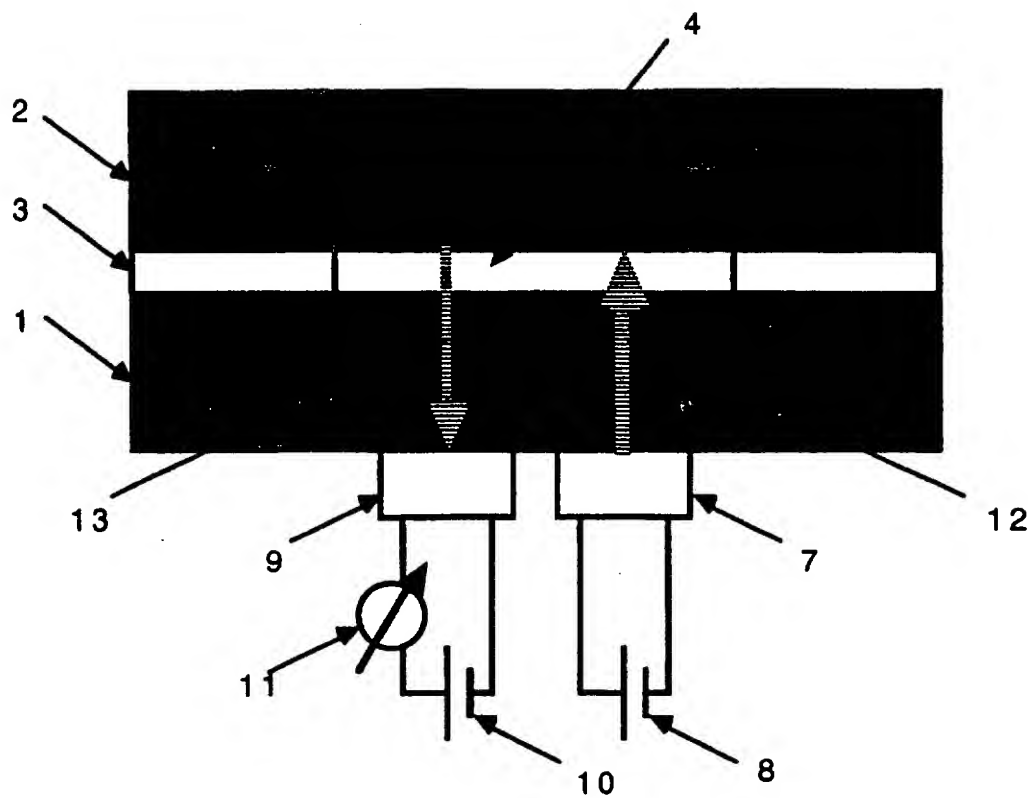


Fig. 2

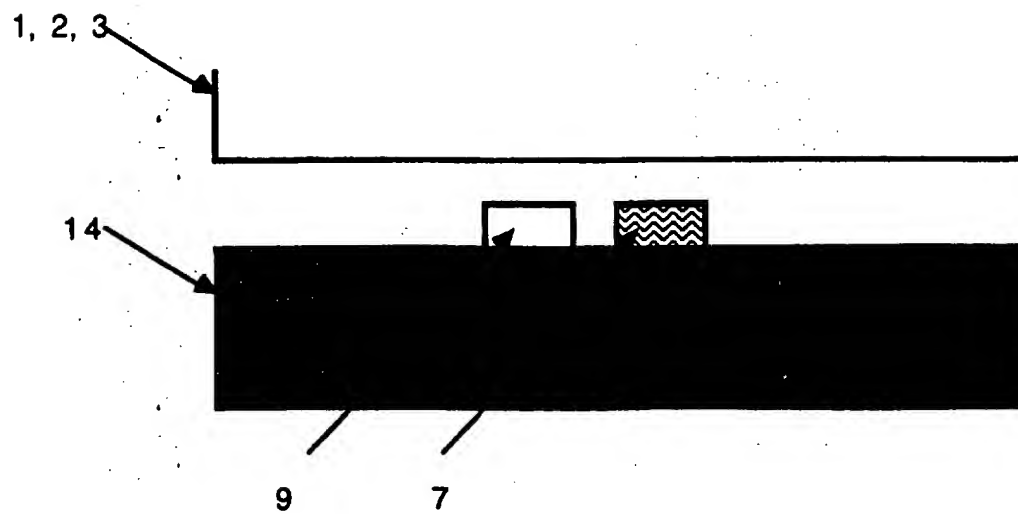


Fig. 3

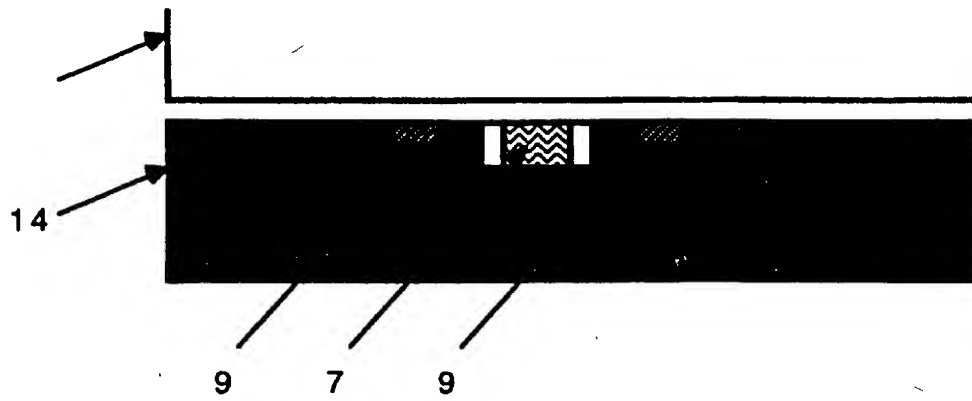


Fig. 4

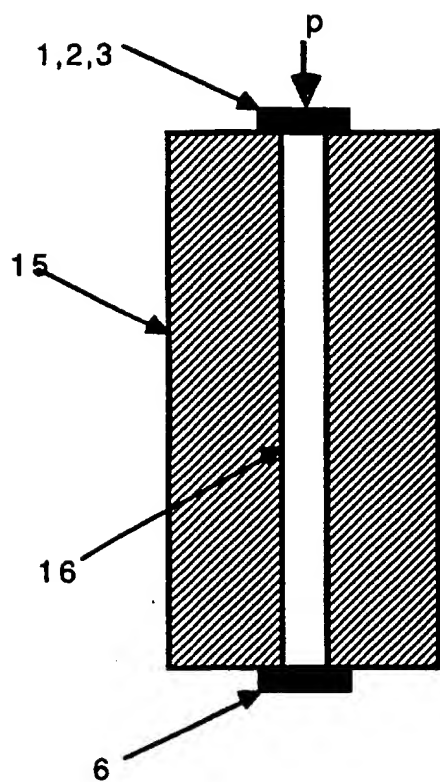


Fig. 5

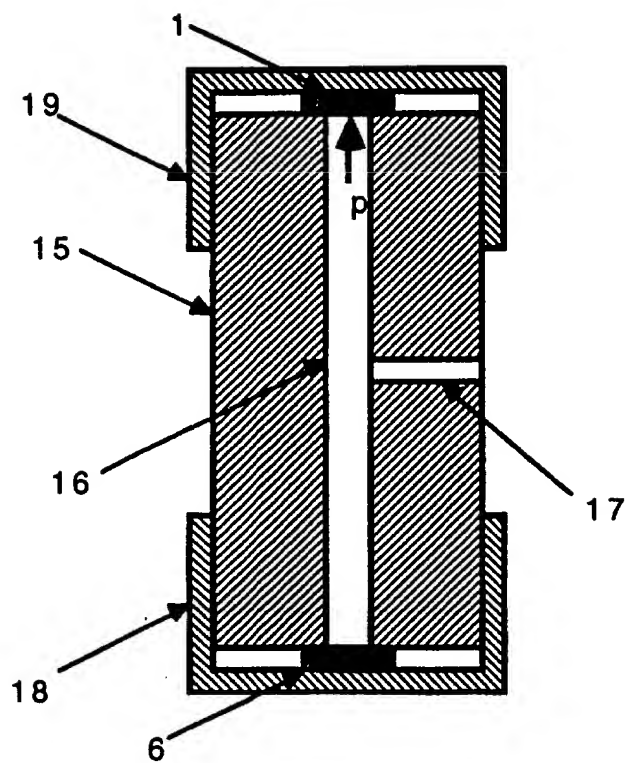
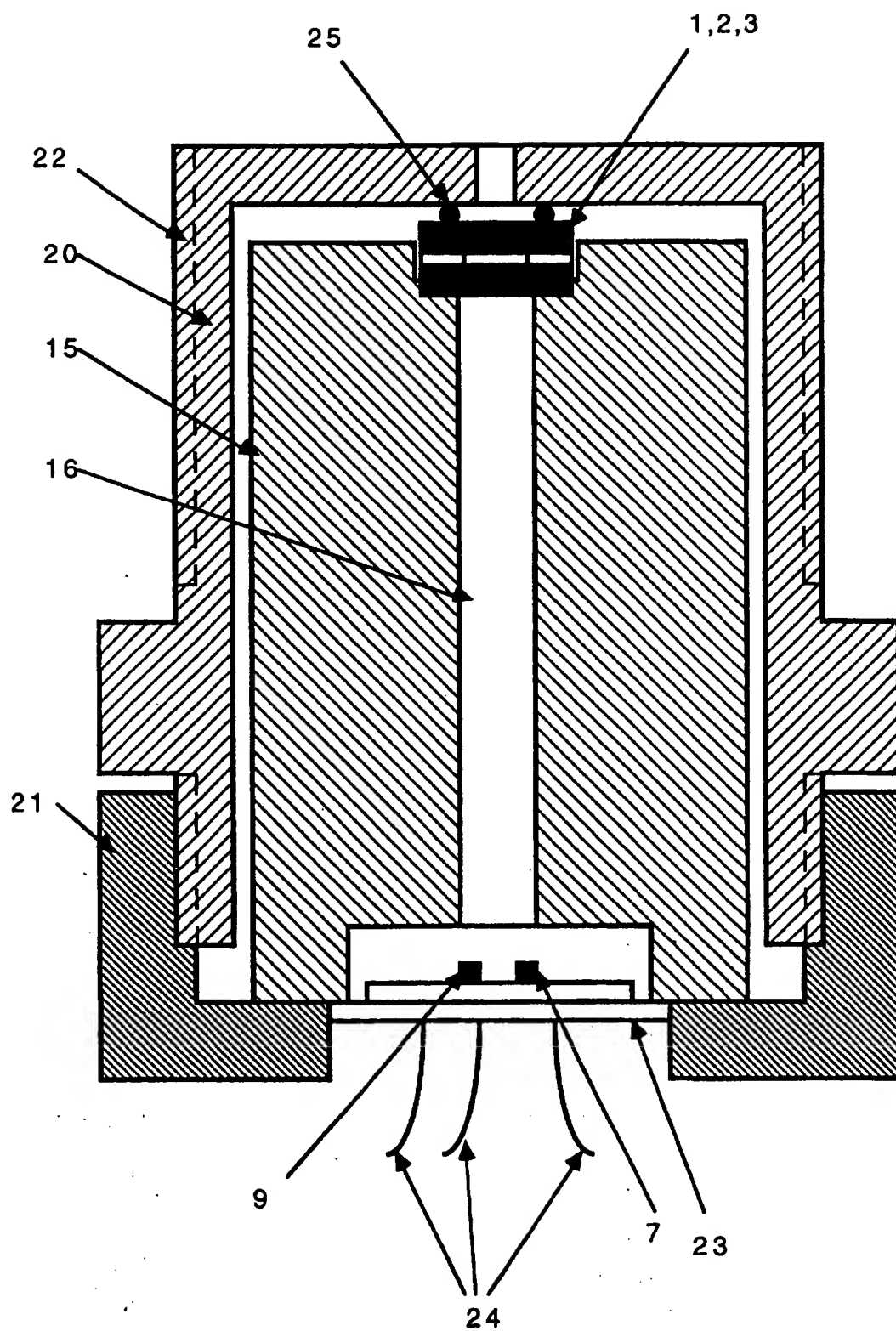


Fig. 6

Fig. 7

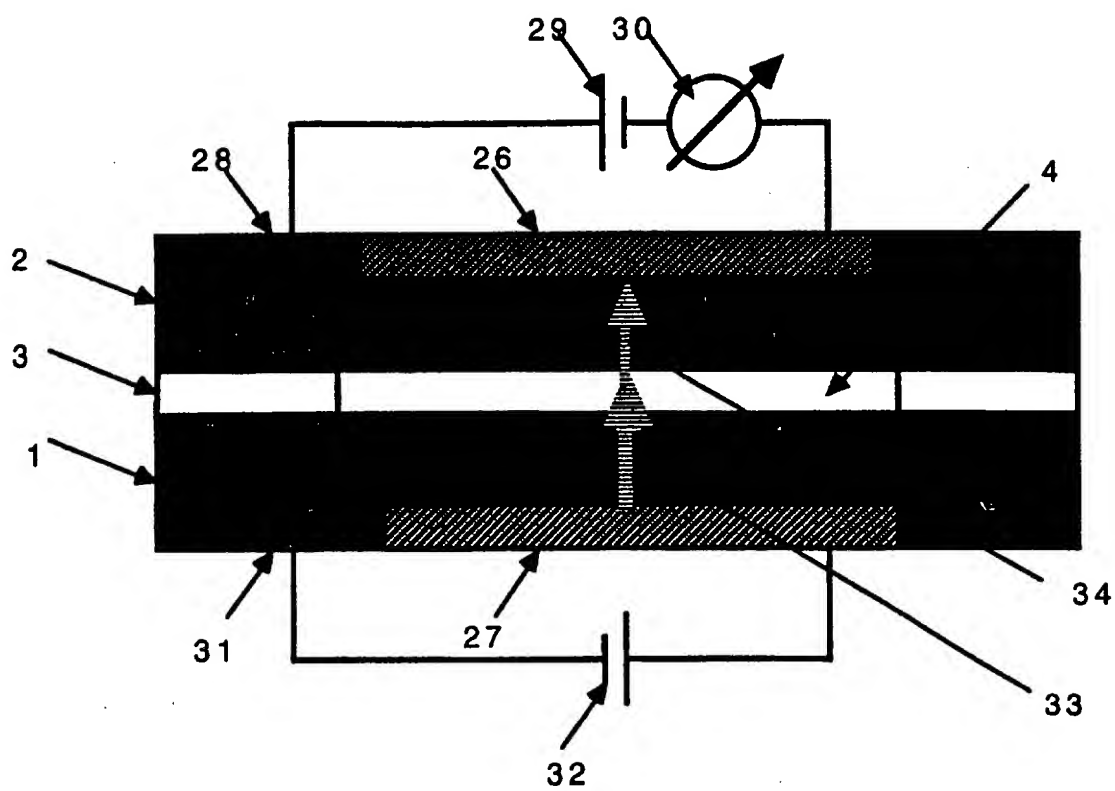


Fig. 8

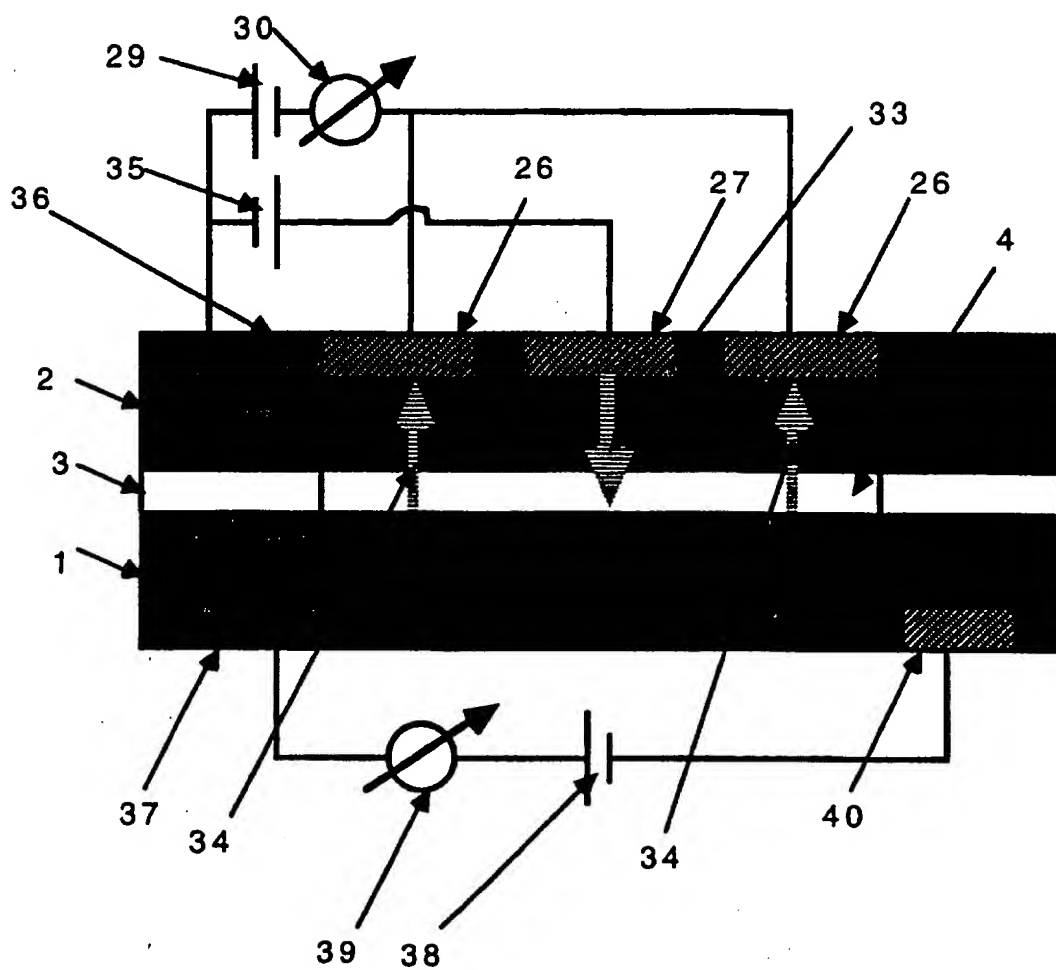
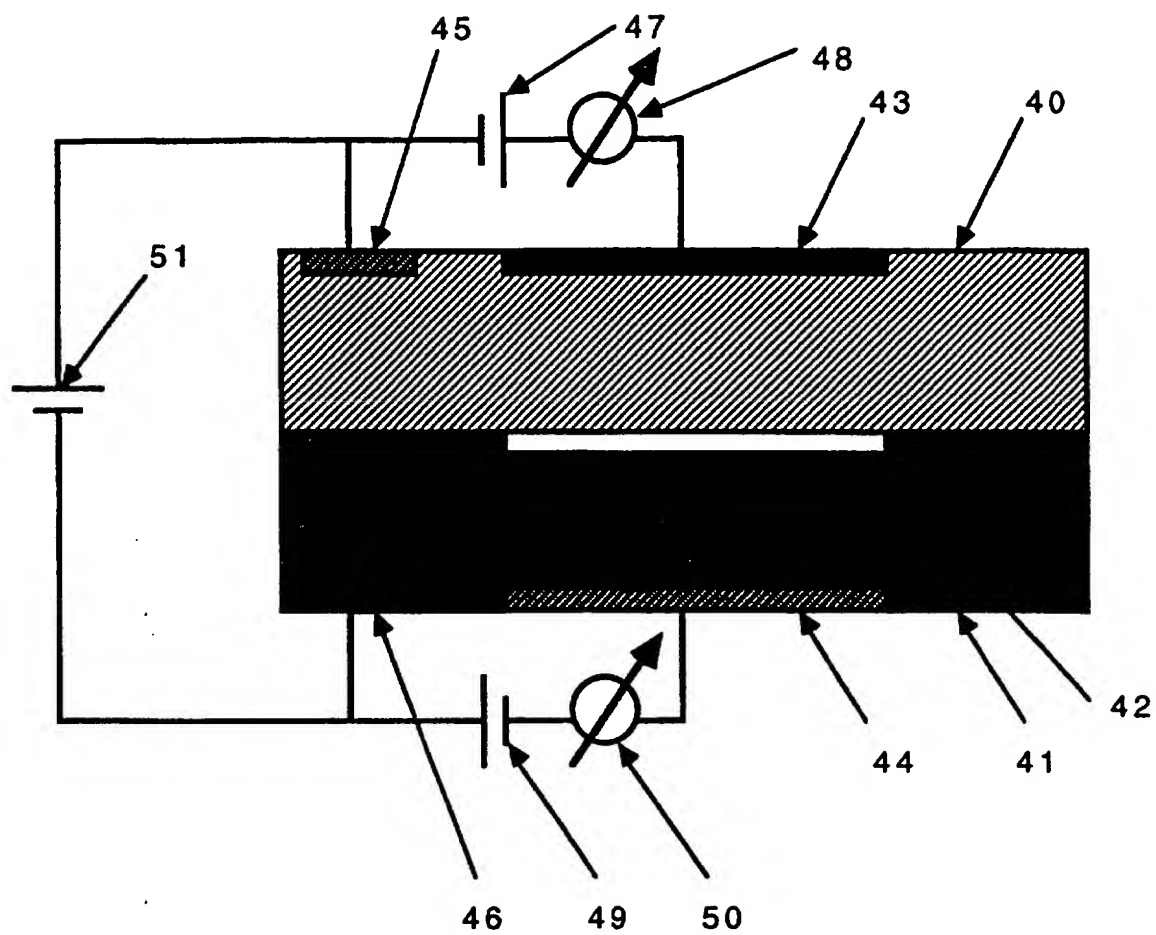
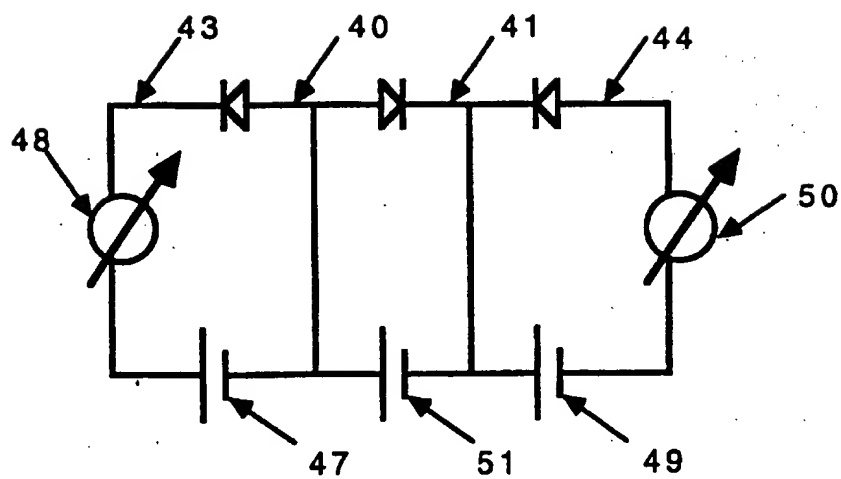


Fig. 9



**Fig. 10**



**Fig. 11**

1  
INTERNATIONAL SEARCH REPORT

International application No.  
PCT/SE 97/00752

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
<b>IPC6: G01L 11/02</b> According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
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<b>SE,DK,FI,NO classes as above</b>		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5128537 A (B.HÄJG), 7 July 1992 (07.07.92), see the whole document	1
Y	--	2-9
X	US 3040583 A (D.POST), 26 June 1962 (26.06.62), see the whole document	1
Y	--	2-9
Y	WO 8804126 A1 (MASSACHUSETTS INSTITUTE OF TECHNOLOGY), 2 June 1988 (02.06.88), see the whole document	2-9
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## INTERNATIONAL SEARCH REPORT

International application No.

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## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4554837 A (H.C.DANBY ET AL.), 26 November 1985 (26.11.85), see the whole document  -----	2-9

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

06/08/97

International application No.  
PCT/SE 97/00752

Patent document cited in search report			Publication date	Patent family member(s)	Publication date
US	5128537	A	07/07/92	EP 0460357 A JP 4232435 A	11/12/91 20/08/92
US	3040583	A	26/06/62	NONE	
WO	8804126	A1	02/06/88	CA 1321009 A US 4926696 A US 4942767 A US 5052228 A	03/08/93 22/05/90 24/07/90 01/10/91
US	4554837	A	26/11/85	NONE	